SO_X RECLAIM STUDY

FINAL REPORT

MODULE 3-D: WET/DRY SCRUBBING TECHNOLOGY FOR CONTAINER GLASS MANUFACTURING PLANT

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I. EXECUTIVE SUMMARY

ETS, INC was commissioned to conduct an engineering evaluation and cost analysis assessment for wet/dry scrubbers to control SO_2 emissions from two glass melting furnaces located at the Owens-Brockway Glass Container Co. (O-I) facility in Vernon, California. Outputs of the program include an evaluation of existing commercially available control technologies, starting with the most effective control technology, recommendations to SCAQMD on various technologies that could potentially be used to achieve additional emission reductions, various concentration targets that could achieved with each technology, the estimated emission reductions, the multimedia impacts, energy impacts of the technologies, and the cost-effectiveness associated with the control technology.

ETS' John McKenna and Jeff Smith visited the site on September 19, 2008. Others at the site meeting included Minh Pham (SCAQMD), Robert Neal, Sandra Guzman, Doug Pittman, and Tony De Fazio (all of O-I). The purpose of the visit was to assess the performance of the facilities existing SO_2 emission control equipment and available space to install future control equipment. An additional objective of the visit was to obtain emission and operational information pertinent to the successful fulfillment of the overall program objectives. Information supplied by the plant was reviewed and analyzed.

From this exercise a gas stream definition (inlet definition) was developed. This information along with a description of the processes was sent to prospective flue gas desulfurization (FGD) technology suppliers in a request for budgetary proposal (RFP) package. Seventeen vendors were contacted and of these, three responded with a quotation. The vendor responses were reviewed for technical approach and the descriptive clarity of that approach, equipment capital cost, and expected usage rates for reactant material and utilities. Installation and operating costs were then developed for each technology approach and compared in spreadsheet format. A report detailing the status of project activities as of October 15, 2008 was submitted to SCAQMD on that date.

ETS has conducted a top down analysis of alternative commercially feasible control technologies for the control of SO_x emissions from the glass plant. This analysis considered the technology which was found to be the most effective in terms of sulfur dioxide removal and which can potentially be installed or retrofitted at O-I. Four vendors (Manufacturer A, Manufacturer B, Manufacturer C, and Manufacturer D) submitted quotes and performance claims and one vendor (Manufacturer E) submitted a description of suggested process improvements on the existing system with a rough budgetary equipment cost. Given the higher removal efficiency (99%), the Manufacturer A wet scrubber was selected as BARCT for the glass furnaces.

A cost-effectiveness determination was executed for the BARCT case and a summary of the results is provided in the following table:

Summary of Recommendations

Equipment	BARCT Level	BARCT Emission Level	Emission Reductions	Cost-Effectiveness
Owens-Brockway A, B & C CEMS	99% control (≤1 ppmv)	0.0058 lbs/ton glass pulled	0.19 tpd	$ 5.0 K/ton SOx

Note: Baseline SO_x emissions used in calculations were from 2005 (SCAQMD database for the period from January 2005 – December 2005)

The following document is to be considered the final report; it provides commentary on all tasks that have been completed, problems encountered and solutions, explanations of technical and economic analysis conducted, as well as the results and conclusions of these exercises. The most cost-effective technology approach for the furnace operations is presented in Section III-C.

II. FACILITY & EMISSION PROFILE

II. A. General Facility & Equipment Description

The facility operates two melting furnaces, a 60 mmbtu/hr furnace and a 100 mmbtu/hr furnace. One United McGill wet scrubber serving only "B" Furnace initially controlled SO_2 emissions, using sodium carbonate "soda ash" as the scrubbing agent. The wet scrubber was removed and a new dry scrubber system was installed on Furnaces "B" and "C". Initially the scrubbing agent used on the dry scrubbers was sodium bicarbonate and later it was changed to sodium sesquicarbonate (Trona). The outlet flue gases from the scrubbers are directed to a common manifold and are then vented to three dry electrostatic precipitators (ESPs) downstream, for particulate emission control. One ESP is on standby while the other two are servicing the gas stream. A simple line diagram showing the operation is attached as Figure 1. The plant has limited space available for additional equipment, approximately a 14' x 20' footprint between two existing scrubbers. In addition O-I personnel indicated that the height of any new equipment could not exceed 30 feet above the top of the existing scrubbing vessels. A request was made of O-I to provide us with dimensional information pertaining to available space for the Manufacturer A equipment footprint. They stated that there is space available. Horizontal distance is 63' depending on the location of the ducting out of the pieces of equipment. This does not take into account the vertical distance which will depend on location of entry to the stream.

II. B. Current Emission Profiles in 2006 and 2008

Continuous emissions monitoring (CEMs) data was provided for all three ESP stacks (A, B, C) for years 2006 and 2008 (January through August). The CEMS data was supplied in spreadsheet form with one row per 15-minute or 1-hour average of all recorded system variables. The total number of rows ranged from about 3500 for the year 2008 unit to about 7500 for year 2006. Examination of the data showed a characteristic that required investigation before estimating statistics. For all three ESP stacks, reported data showed long strings of 10 ppm SO_2 concentration when operating with typical flow rates, but at reduced temperature (ambient up to a few hundred °F). These periods accounted for up to 35 percent of time in service. While such operation may be typical, the constant value of exactly 10 ppm (to 10 or more decimal places) suggests that the CEM was not giving a true reading. However these readings were in included in statistics provided with the CEM data and provided a misleading average concentration for control-equipment design. Eliminating data from periods reporting 10 ppm shifted the average concentration through the year to 92 ppm from 60 ppm. Table 1 provides the results of our statistical analysis of the CEMS data for glass furnaces. Summaries of the stack gas SO_2 concentration, temperature, and flow rate data gathered throughout the project from various sources for ESP A, ESP B, and ESP C are shown in Tables 2, 3 and 4.

III. CONTROL TECHNOLOGY-FEASIBILITY ANALYSIS

III. A. Critique on SCAQMD Preliminary Draft Report

Chapter 7 of the SCAQMD report provides a description of the Tri-Mer Cloud Chamber however the chapter does not provide information on other control approaches, nor does it address the possibility of improving the performance of the existing system. Based on the site visit it appeared that the existing "scrubbing system" was being operated in a manner to meet the existing code rather than performing at the maximum SO_2 removal level possible.

III. B. Literature Research on Control Technology

A search was conducted to identify studies and technical presentations and papers relevant to control of SO_2 emissions from glass melt furnaces. Sources for this information included Air Waste Management Association (AWMA), McIlvaine, USEPA, Industrial Clean Air Companies (ICAC), Glass Manufacturing Industry Council, the Internet, and direct communication with personnel contacts. A list of reference documents is shown in Table 5.

III. C. Discussion of Control Technology & Potential Emissions Reductions

An Australian manual printed in 2004 " Emissions Estimation Technique Manual for Glass and Glass Fibre Manufacturing" stated that both wet and dry scrubbing systems employing both ESPs and baghouses have been successful in the U.S.

Dry Scrubbing

The AWMA text "Air Pollution Control Engineering" states that dry scrubbing using Tesisorb with or without limestone addition has been used. SO_2 removal efficiencies of 95% and above were reported at a stoichiometric ratio of 1.0. In the system described in the text, a baghouse was used, after the reagent injection, for particulate control and perhaps additional reaction.

Wet Scrubbing

The wet system described in the literature employed a venturi scrubber and packed bed scrubber with liquid sodium hydroxide as the scrubbing agent and was capable of 95% removal. The system reportedly had high-energy consumption and this along with the complexity of handling and treatment of the liquid discharge has been a criticism of this approach.

Dry Injection

Another approach was the injection of a dry material such as sodium sesquicarbonate (Trona) into the hot gas stream to react with the SO_2 upstream of either a baghouse or ESP. The reacted Trona is removed form the gas stream using either of the aforementioned particulate control devices. Major equipment components included a reagent storage vessel, reagent grinding mill (Trona particle size is a critical parameter), and duct injection system. In addition to particle size, gas moisture content, retention time and normalized stoichiometric ratio (NSR) of the reagent to SO_2 are important considerations.
Systems with low efficiency requirements can operate at an NSR of less than 1, while higher removal (over 80%) will require an NSR of 1.2-1.7. Typically systems are designed to provide 75-85% removal efficiencies. A generic Trona injection system is shown in Figure 2. Suppliers of the Trona include FMC and Solvay Chemicals. A paper presented by Solvay indicated that in addition to the parameters mentioned above, gas temperature at the injection point is important. This paper is interesting in that the tests were conducted on a glass furnace operation located in California.

The following provides a description of the technologies proposed by the four vendors that supplied budgetary quotations and the one vendor that supplied a recommendation for process improvements to the existing Trona system:

Manufacturer A

The proposed Manufacturer A technology is a wet scrubbing system using NaOH (sodium hydroxide) in a 50% solution as the scrubbing agent. This system is a complete package including a quench section and packed bed scrubber that are integrated in one vertical housing. There were two identical systems proposed. Each system comes complete with all necessary pumps, reagent storage tanks, system fan, and stack.

Manufacturer A also has a technology which simultaneously treats submicron, fine, coarse and condensable particulates plus all soluble acid gases and caustic fumes with a high degree of effectiveness (typically 99% or greater). Manufacturer A personnel indicated that the costs for this system would be much higher than the wet scrubber they proposed due to the fact that it is a multi-pollutant technology.

Manufacturer B

The proposed Manufacturer B technology consists of two identical wet scrubbing systems. The scrubbers use a 25% NaOH solution as the scrubbing medium. Each system consists of an inlet quench duct, a rotating fluidized bed scrubber with integrated mist eliminator, controls, recirculation pump, and associated piping and valves. The proposed system did not include a system fan.

Manufacturer C

The Manufacturer C system employs dry hydrated lime ($Ca(OH)_2$) as the reactant. The system consists of five major components; reaction tower, distribution venturi, fabric filter, recirculation system and fresh reagent storage/delivery system. In this technology process gases enter into the reaction tower near the bottom and flow upward to the distribution venturi at the base of the tower. The gas turns upward and is accelerated thru the venturi throat. The new and recycled reagent is mixed with the gas stream at a point above the venturi throat. New reagent is pneumatically conveyed from the storage silo to the reaction tower. From the tower the gases are directed to the baghouse, and the collected material is either recycled to the process or disposed of. This technology would combine the furnace process gas streams into one air pollution control system and would replace the existing scrubbers, ESP's, and associated ductwork.

Manufacturer D

The proposal offered by Manufacturer D combined the gases after the hot ESP into one wet scrubber using a 20 % NaOH solution as the scrubbing reagent. The feed gas enters the top of a vertical duct and collides with the scrubbing liquid that is injected upward through a large bore injector or Reverse Jet Nozzle. The Reverse Jet nozzle is a very large bore, open throat nozzle that creates a full cone liquid flow that is essential to producing the required Froth Zone. The Froth Zone creates a very high rate of liquid surface renewal and efficiently quenches the gas to the adiabatic saturation temperature and absorbs the SO_2. After contacting, the gas-liquid mixture enters a separation vessel where the liquid drops to the sump of the vessel and the gas travel upward through the vessel. The collected liquid is recycled back to the circulation pump and flows to the Reverse Jet Nozzles.

Manufacturer E

This recommendation offers the advantage of upgrading some of the existing equipment to optimize the SO_2 removal performance. This would consist of increasing the capacity of the existing mills and the injection blower pressure. The revamping of the system would also include upgrading the system control package. The proposal recommends a test trial to evaluate later generation Trona products and to optimize system controls and operation.

Best Available Retrofit Control Technology (BARCT)

ETS has conducted a top down analysis of alternative commercially feasible control technologies for the control of SO_x emissions from the glass plant. This analysis considered the technology which was found to be the most effective in terms of sulfur dioxide removal and which can potentially be installed or retrofitted at Owens-Brockway.

Four vendors (Manufacturer A, Manufacturer B, Manufacturer C, and Manufacturer D) submitted quotes and performance claims and a fifth vendor (Manufacturer E) submitted a list of recommendations to optimize the existing Trona injection system. Manufacturer C proposed a dry fluid bed scrubber in conjunction with a baghouse and hydrated lime reagent achieving 90% removal efficiency. Manufacturer A quoted a wet scrubbing system with 50% sodium hydroxide as the reagent achieving 99% removal efficiency. Manufacturer B quoted a wet scrubber employing 25% sodium hydroxide as the reagent capable of 95% efficiency. In addition Manufacturer D also quoted a wet scrubber using 20% sodium hydroxide as the reagent with an efficiency of 95% (See a vendor proposal comparison in Section V. E. of the Confidential Appendix).

Given the higher removal efficiency (99%), the Manufacturer A Wet Scrubber was selected as BARCT for the glass furnaces.

While the quotes included "performance guarantees" it should be noted that these were budgetary quotes and we would expect the final quotes to have the guarantees tied to specific operating conditions and ranges. In addition there is the need to rigorously examine the installation list of these vendors and possibly visit some reference sites to verify good long term operation.

In light of the BARCT, utilization of sodium hydroxide and the need for disposal of the sodium reaction product waste stream needs to be considered. From the small amount of sodium salts produced from the Manufacturer A wet scrubber (blowdown rate of 4.7 gpm per scrubber with two scrubbers required) the impact on effluent treating systems should be small. However, a budgetary cost ($225 K) has been added to the scrubber equipment cost for the treatment of the waste stream from the scrubbers. There are several different options that could be considered depending on the site-specific requirements:

1) The liquid blowdown from the scrubbers could be sent to a storage tank and recycled back to the furnaces for the batch wetting process.
2) The blowdown could be sent to a storage tank and then to an energy efficient dryer for liquid evaporation. The solid waste could then be placed in a hopper and recycled back to the furnaces.
3) The blowdown could be sent to a storage tank and then sprayed into the duct ahead of the precipitators to evaporate the water and collect the dry particulate in the ESP's.
4) The blowdown could be sent to a storage tank and ran through a small skid-mounted (app. 6'x 6') filtration system prior to discharge to the local sanitary sewer system.

Further investigation would be required to determine the best alternative for the site, but the capital cost implications would roughly be the same.

Other environmental and cross-media impacts from the scrubber include utility usage, water, and solid waste treatment or disposal. Included are annual quantities of electricity, 939,800 kWh; water, 20 million gallons; wastewater, 5 million gallons; and solid waste treatment, 20 tons.

In considering a curve of cost-effectiveness versus level of control there are two considerations. Firstly, will the control device capital cost vary with improved efficiency and secondly, will the operating cost increase with increasing efficiency. Since the capital cost is driven largely by the gas volume and since the volume is essentially constant there is little if any change in the capital cost over the considered range of efficiencies. With respect to operating cost versus efficiency, in the case of sodium hydroxide, while the utilization does increase with increasing efficiency, the cost of the sodium hydroxide was low enough to minimize the impact of efficiency on cost. Thus the merit of plotting a curve of cost versus efficiency seemed of little value.

III. D. Identification of Relevant Vendors and Contact Status

ETS has completed a top-down analysis, starting with the commercially viable control technology that is most effective and can be potentially installed or retrofitted at O-I.

In addition to in-house resources and personal contacts within the air pollution control industry, ETS contacted both the Institute of Clean Air Companies (ICAC) and the Council of Industrial Boilers Association (CIBA) for assistance in identifying suitable FGD equipment suppliers. These vendors were contacted and supplied with a request for a technical response to the RFP shown in Table 6**.** The vendors were asked to provide a Budgetary Equipment Cost and Estimated Annual Operating Cost at the following three levels of performance:

1) Lowest achievable level of efficiency with guarantee
2) Next lowest achievable level of efficiency with guarantee
3) Most comfortable achievable efficiency with guarantee

The purpose of this RFP was to eliminate the non-responsive or those with technical limitations (when considering the site specific demands at Owens Brockway), thus, establishing a list of viable vendors, their technical approach, and the level of SO_2 removal they would guarantee.

Of the seventeen vendors supplied with the request, five (5) provided a response. It is felt that in these five responses we had the opportunity to review a variety of technology options running the gamut from dry induct injection scrubbing, dry scrubbing to wet scrubbing.

The list of vendors, contact person and comments on the status of their proposal efforts is shown in the Section V. F. of the Confidential Appendix.

IV. COST ANALYSIS

IV. A. Approach and Basis for Equipment Sizing and Cost Estimates

The approach to developing the cost estimates initiated with contacting FGD equipment vendors for their inputs on performance, capital and expected operating costs. The request of vendors for a technical response mentioned in Section III. C. of the report was the first step in this process. The intent was to compare the estimated costs of installing new equipment with those costs of modifying existing equipment.

For each technology approach we began by preparing a Discounted Cash Flow (DCF) cost analysis. The DCF approach determines the value of a project using the time value of money by estimating all future cash flows and discounting them to determine the equivalent present value cost. For consistency with other AQMD rule development projects and Air Quality Management Plan (AQMP), present value (or present worth value, PWV) was estimated with the following equation:

$$PWV = C + (CF_1 \text{ x } A) – (CF_1 \text{ x } S) + SUM\ (CF_{2,n} \text{ x } F_n)$$

Where:

C = Capital cost, \$, a single payment

A = Annual cost, \$/yr, a series of uniform payments

S = Annual savings, \$/yr, a series of uniform negative payments

F = Future cost, \$, a single payment in a future year

CF_1 = Conversion factor from compound interest tables of the formula

$[(1 + i)^n – 1]/[i \text{ x } (1 + i)^n]$ where i = fractional interest rate and n = the nth year from the beginning. Used with a series of uniform payments from 1 to n.

$CF_{2,\,n}$ = Conversion factor from compound interest tables of the formula $1/(1 + i)^n$. Used with a single payment at any year n.

To be consistent with AQMD cost-effectiveness analysis, a 4% annual interest rate was used in the calculations.

The DCF included all anticipated capital and expense costs associated with the project or measure evaluated. The capital portion of those costs included materials, labor, and other directs, as well as engineering, management, taxes, shipping, and various indirect costs incurred for the particular control technology. Every cost item incorporated in the estimate was site and equipment specific. Wherever possible, cost elements were individually listed, quantified, and costed via the use of applicable unit rates. In that fashion (i.e., “line-item” estimating, in lieu of purely factored costs), the relative precision of the overall estimate was optimized. Also, reviewers of the cost development sheets had the greatest insights into how the estimates were assembled; they were then more easily able to adjust the results to reflect scope changes or improved data.

Whenever possible vendor/manufacturer budgetary quotes and local material/labor costs were used in our estimates. When these costs were not available, ETS' standard cost estimating methodologies for material and labor were used to complete the pricing exercises.

IV. B. Equipment Cost Information

A short list of vendors was identified and they were asked to provide a budgetary cost estimate for the supply and installation of their equipment. The vendor was also requested to identify any utilities needed and their expected rate of usage. The vendor was also asked to identify the amount and type of waste generated by the process. If the vendor's approach was to modify or retrofit existing hardware, he was requested to supply a cost estimate for those activities. For example, if the proposed approach was that of dry or wet injection upstream of the baghouse, the proposal should have included an estimate for all required equipment hardware, reagent storage vessels, reagent feed control instrumentation, engineering, construction and installation, etc., as well as pre-engineering costs such as site testing activities to locate the reagent injection site to optimize system performance with respect to SO_2 control and reagent utilization.

IV. C. Annual Operating Costs and Cost-Effectiveness Analysis

Operating costs were developed for each of the short-listed approaches. In conducting this exercise we evaluated (and modified as needed) vendor-supplied information such as utility usage, system pressure loss, waste stream rates, etc. and input them into our costing calculations. Among the analytical methods used were those described by Vatavuk in his text; "Estimating Cost of Air Pollution Control" and the "EPA Air Pollution Control Manual". These methods have traditionally used an annualized cash flow for cost-effectiveness analysis; however for this program we used a Discounted Cash Flow method at a 4% real interest rate and 7.5% tax. Labor costs were developed using rates identified in the government labor rate website. The cost-effectiveness analysis also included an evaluation of the technology's potential for reducing multiple pollutants, if any, that exist concurrently over the same useful life of the control equipment.

AQMD requires comparative cost and cost-effectiveness information for control of SO_2 at several concentrations and with several types of control systems. This information was used to determine economic and regulatory reasonableness of requiring any of the various control combinations. Equipment vendors furnished cost estimates for systems they can supply. Elements of the cost included, either by the vendor or by contractor personnel, categories such as foundations; structural steel; equipment; duct, piping and mechanicals; electrical and controls; waste disposal; miscellaneous; and contingencies. Each category was further divided into materials and equipment, labor, and other costs. As complete sets of costs were collected for each concentration and equipment type, a spreadsheet program was used to analyze the data. The discounted cash flow method, as described above, was used to arrive at present worth value. Cost-effectiveness of each equipment type/SO_2 reduction quantity (mass of SO_2 removed from a plant's emission stream over the life of the control) was estimated in $/ton of pollutant removed by dividing PWV by the mass of SO_2 removed. A cost-effectiveness determination was executed for the BARCT case and a summary of the results are provided in Table 7.

IV. D. Inputs for Cost Estimation Modeling

A spreadsheet model uses case-specific vendor quotes for major equipment systems and for some elements of installation, operation , and maintenance. These quotes may include materials, labor hours, and utilities. Where information is not available from the major equipment vendors of a control system supplying the base quote, other vendors may be contacted for estimates of smaller pieces of equipment, supplies, and construction work. If such contacts are not productive, literature sources may be sought for current costs and estimates of operating labor, materials, supplies, and utilities.

The model used for this work allows for inputs from all these categories. The input section of the model provides a series of cells that, under the heading of structural steel for example, allow for primary, secondary, and platform steel in tons or square feet. Unit costs are obtained and applied to the steel quantities for a total cost for steel not included in equipment quotes. Further, unit times for erecting the steel (labor hours per ton) can be estimated for specific jobs or obtained from sources such as R.S. Means construction cost manuals. Total labor cost for erection is number of tons of steel times the unit cost of labor. If other costs such as buying a prefabricated storage shed installed at the job site are needed, they can be entered into the model. All costs within the category of structural steel are summed, and the remaining categories are also summed and added together to estimate a total equipment and installation cost. Table 8 shows the major categories within the model.

To provide a convenient means of handling labor and utility costs that are used across categories, separate spreadsheet tabs are constructed for storing these data. As changes occur to, for example, the cost of electricity or the cost of an electrician, new costs are entered into the data tabs and referenced by the main model tab.

Similarly to the equipment installation, ongoing operation and maintenance sections of the model apply unit costs to expected quantities of materials and labor to keep the equipment going. Space is provided for estimating ongoing costs annually, both constant costs and periodic costs such as major scheduled maintenance at five-year intervals. These costs are calculated on a line-by-line basis that can be used for financial estimates and for visual examination of changes in costs. Although not used for the AQMD work, the model can estimate costs with assumed annual escalation rates for labor categories, materials, supplies, and utilities. The model can also begin costing up to four years before startup, with capital expenditures apportioned as annual percentages for each year (see Table 9).

Cost-effectiveness over the control system life is found by dividing present worth value (PWV), described elsewhere in this report, by total tons of emission reduction. The model contains cells that collect values for the PWV equation terms, and adds those terms for a total PWV. Cells are also provided for baseline emissions taken from plant records of stack tests or CEM data. Design efficiency for the control system is applied to the baseline emission rate for an emission reduction (tons), which is the denominator in the equation for finding cost-effectiveness.

For a list of assumptions/information that ETS used in the cost analyses for the glass furnaces, please see Table 10.

Table 1. CEMS Data from Electrostatic Precipitator (ESP) Stacks A, B, & C

Statistic	ESP A 2008				ESP B 2008				ESP C 2008			
	SO2 lb/hr	SO2 ppmw	Gas flow wscfh	Gas Temp °F	SO2 lb/hr	SO2 ppmw	Gas flow wscfh	Gas Temp °F	SO2 lb/hr	SO2 ppmw	Gas flow wscfh	Gas Temp °F
Count for rows with SO2 >10 ppm	3,582	3,506	3,506	3,510	4,099	4,001	4,027	3,993	4,664	4,617	4,583	4,602
max	45.1	390.91	830,939	748.5	48.676	365	921,031	722.8	82.3	720.39	826,729	750
min	0.097	10.7	113,651	88.8	0	10.0	13,639	67.2	0.000	10.0	0	67
average	10.2	92.4	675,204	586	11.8	101	688,179	575.38	12.9	120	649,914	637
median	9.09	85.2	750,313	614	11.7	96.1	764,521	616	12.4	118	711,598	652
stdev	6.45	49.8	173,318	107	6.50	43.7	221,838	123	6.4	58.3	144,970	76
relative std	0.633	0.539	0.257	0.183	0.549	0.433	0.322	0.213	0.501	0.485	0.223	0.119
Statistic	ESP A 2006				ESP B 2006				ESP C 2006			
	SO2 lb/hr	SO2 ppmw	Gas flow wscfh	Gas Temp °F	SO2 lb/hr	SO2 ppmw	Gas flow wscfh	Gas Temp °F	SO2 lb/hr	SO2 ppmw	Gas flow wscfh	Gas Temp °F
Count for rows with SO2 >10 ppm	6,082	6,024	6,096	6,063	6,422	6,402	6,452	6,418	7,352	7,342	7,549	7,360
max	40.3	316	946,431	722.9	42.339	358	1,014,579	737	41.8	325	1,241,806	787
min	0	10.2	26,668	52.6	0	10.1	16.0	48.8	0	10.0	0	77.9
average	10.4	85.5	735,239	637.266	8.56	71.2	715,108	602	9.2	80.0	687,276	641
median	8.75	72.4	775,486	651	7.60	65.1	739,859	620.6	8.88	74.4	743,120	658
stdev	6.77	52.5	150,779	69.1	5.20	38.9	180,900	86.9	5.18	38.8	193,022	75.0
relative std	0.649	0.614	0.205	0.108	0.607	0.546	0.253	0.144	0.560	0.485	0.281	0.117

Table 2. ESP A - SO_2, Temperature, and Flow Rate Information

ESP A - SO_2 , Temperature and Flow Rate Information												
Data Source	**Average SO_2 (ppm)**	**Max. SO_2 (ppm)**	**Average SO_2 Rate (lb/hr)**	**Max. SO_2 Rate (lb/hr)**	**Average SO_2 Rate (tons/day)**	**Max. SO_2 Rate (tons/day)**	**Average Stack Temp. (° F)**	**Max. Stack Temp. (° F)**	**Average Stack Flow (wscfh)**	**Max. Stack Flow (wscfh)**	**Average Stack Flow (dscfm)**	**Calculated Stack Flow (acfm)**
2008 CEMS	92.4	391	10.2	45.1	0.122	0.541	586	749	675,204	830,939	9,847	22,210
2006 CEMS	85.5	316	10.4	40.3	0.125	0.484	637	723	735,239	946,431	10,722	25,363
Site Visit 9/19/08 Control Room Snapshot ***Partial Load on Furnace**	30.1						444		372,400			10,586
2003 Compliance Emission Test (6/12/03)	N/A			N/A			683				15,582	38,764
2002 Compliance Emission Test (6/10/02)	N/A			N/A			658				10,641	27,266
Note 1:Used 12.5% moisture for DSCFM calculation												
Note 2: No correction for pressure in ACFM calculation (no data)												

Table 3. ESP B – SO_2, Temperature, and Flow Rate Information

ESP B - SO_2 , Temperature and Flow Rate Information												
Data Source	**Average SO_2 (ppm)**	**Max. SO_2 (ppm)**	**Average SO_2 Rate (lb/hr)**	**Max. SO_2 Rate (lb/hr)**	**Average SO_2 Rate (tons/day)**	**Max. SO_2 Rate (tons/day)**	**Average Stack Temp. (° F)**	**Max. Stack Temp. (° F)**	**Average Stack Flow (wscfh)**	**Max. Stack Flow (wscfh)**	**Average Stack Flow (dscfm)**	**Calculated Stack Flow (acfm)**
2008 CEMS	101.0	365	11.8	48.7	0.142	0.584	575	723	688,179	921,031	10,036	22,398
2006 CEMS	71.2	358	8.56	42.3	0.103	0.508	602	737	715,108	1,014,579	10,429	23,882
Site Visit 9/19/08 Control Room Snapshot ***Partial Load on Furnace**	26.6						360		241,800			6,235
Source Test July 2005 (e-mail from Minh)	35.0											
2003 Compliance Emission Test (6/27/03)	49.1		2.83		0.034		614				13,003	30,962
2002 Compliance Emission Test (6/11/02)	62.0		7.7		0.092		655				12,508	30,659
Note 1:Used 12.5% moisture for DSCFM calculation												
Note 2: No correction for pressure in ACFM calculation (no data)												

Table 4. ESP C – SO_2, Temperature, and Flow Rate Information

ESP C - SO_2, Temperature and Flow Rate Information												
Data Source	**Average SO_2 (ppm)**	**Max. SO_2 (ppm)**	**Average SO_2 Rate (lb/hr)**	**Max. SO_2 Rate (lb/hr)**	**Average SO_2 Rate (tons/day)**	**Max. SO_2 Rate (tons/day)**	**Average Stack Temp. (° F)**	**Max. Stack Temp. (° F)**	**Average Stack Flow (wscfh)**	**Max. Stack Flow (wscfh)**	**Average Stack Flow (dscfm)**	**Calculated Stack Flow (acfm)**
2008 CEMS	120.0	720	12.9	82.3	0.155	0.988	637	750	649,914	826,729	9,478	22,420
2006 CEMS	80.0	325	9.2	41.8	0.110	0.502	641	787	687,276	1,241,806	10,023	23,795
Site Visit 9/19/08 Control Room Snapshot	58.1						673		812,800			28,959
Source Test July 2005 (e-mail from Minh)	50.0											
2003 Compliance Emission Test (6/13/03)	49.2		3.24		0.039		615				14,870	34,345
2002 Compliance Emission Test (6/12/02)	32.3		3.9		0.047		424				12,143	24,003
Note 1:Used 12.5% moisture for DSCFM calculation												
Note 2: No correction for pressure in ACFM calculation (no data)												

Table 5. List of Reference Documents for Glass Industry

AQMD, 2008. *South Coast Air Quality Management District – Preliminary Draft Staff Report SO_x RECLAIM Part I Allocations, Emissions & Control Technologies,* April 2008.

AUSTRALIAN GOVERNMENT, 2004. *Emissions Estimation Technique Manual for Glass and Glass Fibre Manufacturing,* Australian Government Department of the Environment and Heritage, Version 2.0, May 17, 2004.

AWMA, 2000. *Air Pollution Engineering Manual –Glass Manufacturing,* Aaron J. Teller and Joseph Y. Hsieh, Air & Waste Management Association, 2000.

CARB, 1978. *Feasibility of Installing Sulfur Dioxide Scrubbers on Stationary Sources in the South Coast Air Basin of California.* Prepared by P.P. Leo and J. Rossoff of The Aerospace Corporation for California Air Resources Board, Contract No. A6-211-30, August 1978.

EPA, 2007. *The U.S. Environmental Protection Agency RACT/BACT/LAER Clearinghouse,* 2007. http://cfpub.epa.gov/rblc

HADDAD, 2003. *Full-Scale Evaluation of a Multi-Pollutant Reduction Technology: SO_2, Hg, and NO_x*, Edwin Haddad, Mobotec USA, Inc., Paper # 117.

KLAFKA, 2001. *Air Quality Permit Issuance and Varying Interpretations of BACT in the Flat Glass Industry.* Steven J. Klafka, Kurt W. Jacobsen, and Mark Purcell, presented at the Annual Meeting of the Air & Waste Management Association, June 2001.

MAZIUK, 2005. *Trona Injection Above 700°F to Remove Sulfur Oxides from Flue Gas,* John Muziuk of Solvay Chemicals, presented at ICAC CATS, March 10, 2005.

NESCAUM, 2007. *Five-Factor Analysis of BARCT Eligible Sources – Survey of Options for Conducting BART Determinations.* Prepared by Northeast States for Coordinated Air Use Management (NESCAUM) for the Mid-Atlantic Northeast Visibility Union (MANE-VU), June,1 2007.

PECHAN, 2005. *Update of Control Equipment Data to Support Minnesota Pollution Control Agency (MPCA) Control Equipment Rule – Final Report*, Stephen M. Roe, Ying K. Hsu, Maggie Ma, Holly C. Linquist, E.H. Pechan & Associates, Inc., Report No. 05.06.00X/9446.000 CFMS No. A72995, June 2005.

STATE OF NEW JERSEY, 1997. *State of the Art (SOTA) Manual for the Glass Industry,* State of New Jersey Department of Environmental Protection Air Quality Permitting Program, July 1997

TRIMER, 2007. *Treatment for Fine Particles and Gas Cloud Chamber® Technology and Its Applications.* K. Moss and R. Gravely, 2007.

Table 6. Request for Proposal (RFP) – Glass Furnace

FGD Vendor (Glass) Preliminary Technical RFP

ETS, INC. has been commissioned to conduct a study of SO_2 emission reduction from a glass manufacturing plant.

The Project

The facility operates two melting furnaces, a 60 mmbtu/hr furnace and a 100 mmbtu/hr furnace. Furnace SO_2 emissions are currently controlled by reagent, injected in the exit ductwork of each individual furnace and located upstream of a common manifold connecting the two furnaces to three hot -side ESPs. (A simple line diagram is attached as Figure 1). This and other process modifications have reduced SO_2 levels to approximately 50 PPM; however further reduction of existing levels is required. **If your firm would like to be considered as a candidate supplier, please provide a technical response to the following information. Installation references are also encouraged.**

Flue gas averages/ranges (typical of each ESP exit gas to be used for FGD design is as follows):

Parameter	*average*
Gas Flow Rate (ACFM)	30,000
Gas Temperature (^oF)	675
Pressure (in. wg.)	TBD
Gas Composition	
O_2 (%)	15
H_2O (%)	13
NO_x (ppm)	TBD
SO_2 (ppm)	50-100
Particulate (gr/scfd)	0.008

Your response should include the following technical information:

Process Type (examples; induct injection, spray drying, wet scrubbing)
Process Equipment (major equipment components and weights)
Equipment Footprint (rough dimensional outline)
Reagent Type
Reagent Usage Rate (estimate for min/max conditions)
Reagent Utilization (expected for min/max conditions)
Pressure Loss (across FGD process equipment)
Temperature Loss (across FGD equipment)
Utility Requirements
Glass Furnace Installations & References

Please quote the Budgetary Equipment Cost and Estimated Annual Operating Cost at the following three levels of performance:

1) **Lowest achievable level of efficiency with guarantee**
2) **Next lowest achievable level of efficiency with guarantee**
3) **Most comfortable achievable efficiency with guarantee**

Table 7. Cost-Effectiveness Table – Glass Furnace

Glass Furnace SO_2 Control at 99 % Efficiency		
		Sodium Hydroxide Scrubbers, 2 furnaces
Baseline Emissions	ton/yr	71.5
Emission Reduction	ton/yr	70.8
Equipment Cost	$ million	1.10
Annual Operating Cost	$ million	0.44
Capital Cost	$ million	1.9
Present Worth Value (25 -Year Life)	$ million	8.8
Cost-Effectiveness Factors		
SO_2 Reduction	$/ton	4,988
SO_2 + PM reduction	$/ton	N/A
Note: Baseline SOx emissions used in calculations were from 2005 (SCAQMD database for the period from January 2005 - December 2005)		

Table 8. Major Categories of Costing Model Inputs – Capital Costs

Demolition and Decommissioning
Civil/Concrete
Structural
Equipment
Piping & Mechanical
Electrical & Controls
Misc. Direct & Indirect Costs
Contractor overhead and misc. rentals
Contractor field supervision
Mobilization/Demobilization
Overtime/productivity factor
Freight/shipping
Sales Tax
Commissioning and operating spares
Start-up/initial fill material
On-site training/start-up assistance
FEED engineering through detailed design
Project management

Table 9. Major Categories of Operating and Maintenance Costs

Annual Maintenance Costs
Periodic Maintenance Costs
Additional Operating Costs
Utilities
Natural Gas
Electricity
Water
Wastewater
Cooling Water
Compressed Air
Solid Waste Disposal

Table 10. List of Assumptions for Cost Analysis

The following is a list of the assumptions/information that ETS used in the cost analyses for the glass furnaces:

- Costing is for two scrubbers at one site based on one quote for a single scrubber
- Baseline emissions are taken from 2005 data estimating a rate of 0.196 tpd total for both furnaces (A, B & C CEMS)
- Scrubber control efficiency: 99%
- Life of control equipment: 25 years
- Purchased equipment costs (with auxiliaries, instruments, freight, taxes): $1.1 M for the wet scrubbers
- Add charges for seismic considerations (Zone 4) included in equipment costs (app.$59 K)
- Add charges for wastewater treatment included in equipment costs (app. $225 K)
- Control equipment vendor quotes based on 100 ppm SO_2 at scrubber inlet (0.14 tpd)
- Annual operating costs are $435 K for the wet scrubbers
- Project management costs are based on 1 engineer for 750 hours and 1 manager for 400 hours. (Note: There may be a variation in these numbers depending on the application itself and the nature and size of the engineering company).
- Overhaul (turnaround) maintenance is performed every 5 years starting the fifth year after startup
- Startup is 1 year after the project begins
- Labor rates in $/hr for construction are:
    1. Laborer 90
    2. Civil/concrete worker 90
    3. Structural/iron worker 95
    4. Painter 90
    5. Insulator 100
    6. Mechanical/machinist 105
    7. Vessel/boilermaker 110
    8. Piping/pipe fitter 95
    9. Electrical/electrician 110
    10. Instrumentation/electrician 110
- Utility rates in $/unit during construction are:
    - Natural gas, $7.50/MM Btu
    - Electricity, $0.070/k/wh
    - Water, $4,000/MM gal
    - Wastewater, $6,000/MM gal
    - Cooling water, $0.50/MM gal
    - Compressed air, $0.15/1,000 scf
    - Solid waste disposal, $100/ton

50% NaOH (sodium hydroxide) is $400/ton

Table 10 (continued)

Capital expenditures for equipment purchase and construction are all made in the first year. The spreadsheets for estimating PWV are adapted from a procedure that estimates net present value on a line-by-line (year–by-year) basis beginning a specified number of years before startup (1 to 4). Capital costs for equipment purchase and construction are included in the years preceding startup. This procedure estimates net present values that are different from AQMD's PWV.

Because of this difference the spreadsheet has modifications that use the line-item costs, but regroup them in a manner suitable for use in the PWV equation.

- Categorized costs include:
  - Demolition and decommissioning
  - Civil/concrete
  - Structure
  - Equipment
  - Piping and Mechanical
  - Electrical and controls
- Miscellaneous line items
  - Contractor overhead, 8 % of direct field labor (DFL)
  - Contractor field supervision, 12 % of DFL
  - Mobilization/demobilization, 5 % of DFL
  - Overtime/productivity factor, 12 % of DFL
  - Freight and shipping, 0%, included in equipment cost
  - Sales tax, 7.5 % of materials
  - Commissioning and operating spares, 5 % of materials
  - Startup/initial fill material, 2 % of materials
  - On-site training/startup assistance, 2 % of materials
  - Front-end engineering design, 750 hrs
  - Project management, 400 hrs

Figure 1. Line Diagram of Glass Plant Furnaces

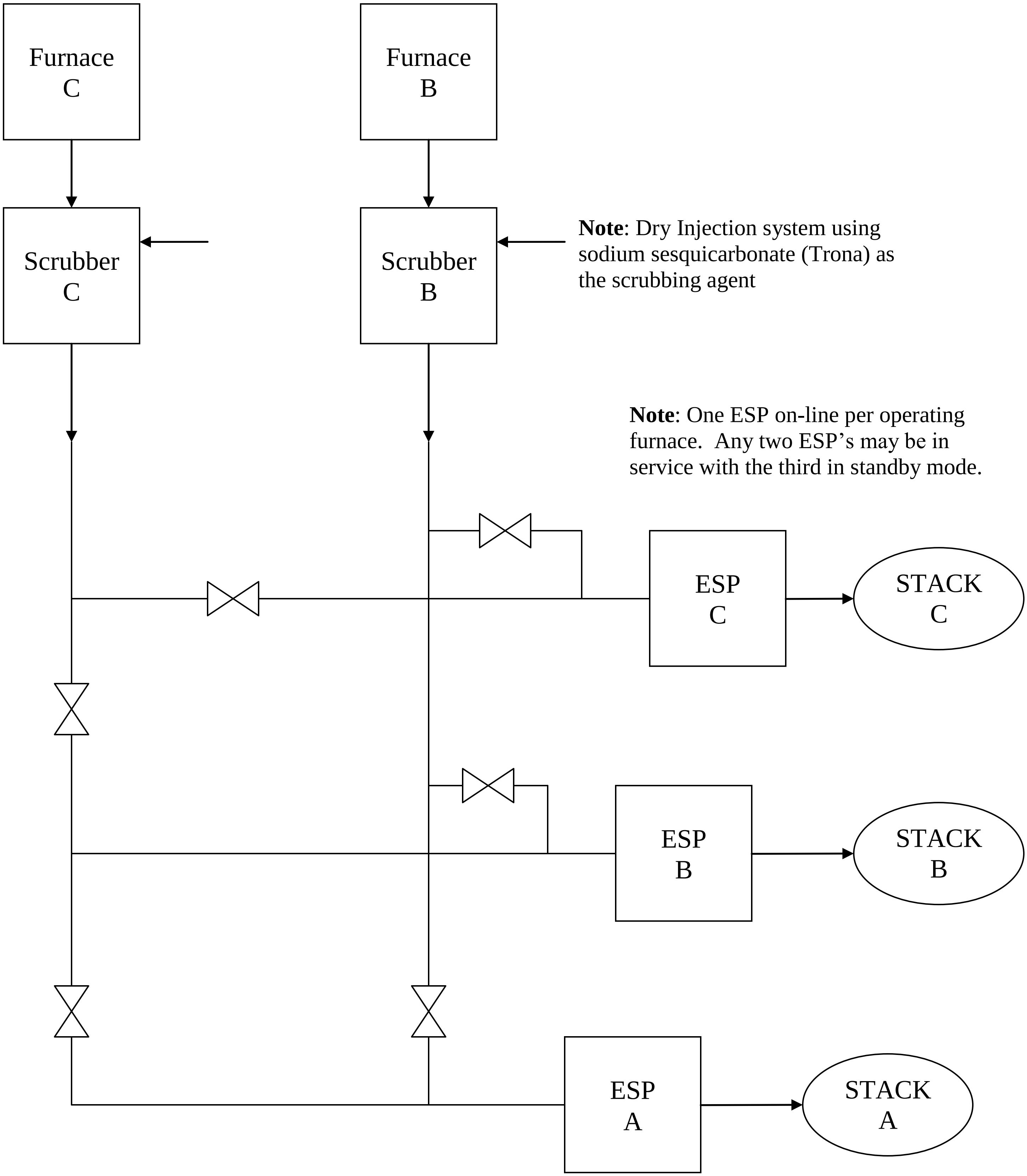
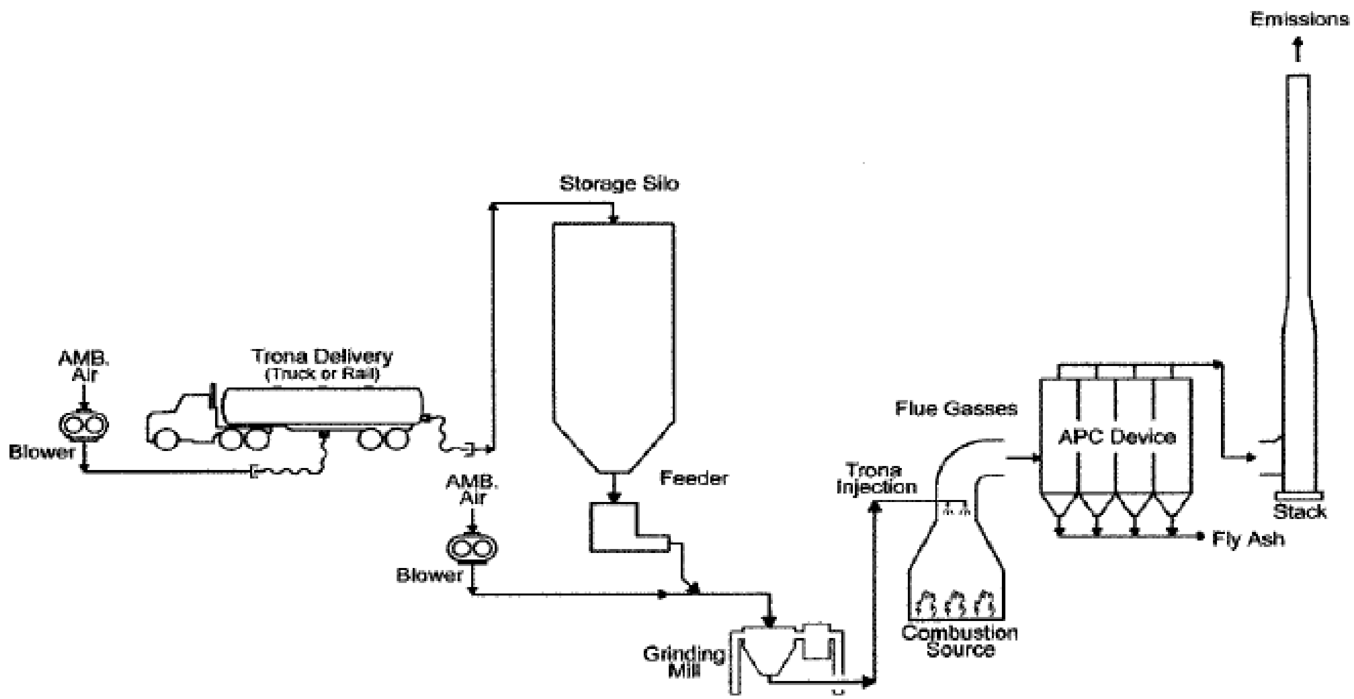


Figure 2. Typical Trona Injection System



Trona Injection System for SO_2 Reduction

Solvay Chemicals, Inc.